EDL Engineering Constraints
Mars 2020
1st Landing Site Workshop

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• Given the “re-flight” nature of Mars 2020, the EDL engineering constraints unsurprisingly look a lot like MSL’s engineering constraints with a few exceptions

• The 2020 opportunity enables higher landing site elevations than were possible with MSL

• Engineering constraints are a discretized set of thresholds
  – Some of these are firmer than others
  – Constraints are interconnected
  – We’ve got a better handle on this now after MSL

• Potential enhancements to EDL are being considered: Range Trigger and TRN
  – Improves landing site access
  – Will affect engineering constraints

• This primer refreshes the MSL constraints for Mars 2020
• Pressure cycle very favorable for 2020
  – Mars orbit eccentricity transfers CO₂ from polar caps to atmosphere
  – Atmosphere significantly more dense than for MSL landing
  – Low risk of dust events

• More density = capability to land safely at higher elevations

• 2020 atmosphere provides significant “no cost” improvements to landing elevation for same landed mass
  – Higher altitude capability
  – More propellant margin

Pre-Decisional: For Planning and Discu
Baseline Engineering Constraints

- Our understanding of MSL capabilities has matured

- Mars 2020 baseline EDL engineering constraints reflect our best knowledge of the MSL as-flown capability translated to the 2020 opportunity

- 2020 opportunity improves altitude capability; other constraints unchanged from MSL as flown

- Constraints will look very similar to original MSL constraints with a few exceptions

- Following slide summarizes the Mars 2020 baseline constraints
<table>
<thead>
<tr>
<th></th>
<th>MSL Capability (in 2011 opportunity)</th>
<th>Mars 2020 Baseline</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipse Size (major x minor)</td>
<td>25 km x 20 km</td>
<td>No change from MSL.</td>
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<td>Site Elevation</td>
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<td>2020 opportunity improves elevation capability.</td>
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<tr>
<td>Approximate Ellipse Major Axis Azimuth</td>
<td>N/A</td>
<td>81°- 112°</td>
<td></td>
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<td>Rocks</td>
<td>≤ 0.5% chance of rock &gt; 0.55 m high in belly pan area</td>
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<td>Approximate MSL test/analyzed capability. Portions of MSL landing site candidates had local CFA of ~30%.</td>
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Potential Enhancements

• Mars 2020 is studying two potential EDL enhancements, as discussed in the SDT report
  – Range trigger: improves landing precision (smaller landing error ellipse)
  – TRN: allows some hazards in the landing ellipse

• Neither option is currently baselined
  – Looking for feedback on the value/necessity of each
    • Does either approach (or their combination) allow access to a high-value site that is inaccessible with the baseline capability?
    • Does either approach (or their combination) change a site accessible only by “go to” into a “land on” candidate?
  – Will look at landing hazards presented by landing site candidates

• Ongoing studies are giving us a better understanding of the costs and potential landing site access benefits
Range Trigger

- Trigger parachute deploy based on the vehicle reaching a navigated range rather than a navigated velocity
  - MSL baseline: deploy the parachute based on reaching a specified navigated velocity (a.k.a. “velocity trigger”)
  - Range trigger: deploy on range within safe velocity limits (sometimes called “velocity constrained range trigger”)

- To successfully execute guided entry, the vehicle already propagates its position from the pre-entry nav state
  - MSL “knew” it was long of the center of the ellipse when it deployed the parachute, but couldn’t do anything about it

- No new hardware is required – only a simple EDL flight software change
• Using range trigger can significantly shrink the landing ellipse
  – ~40% reduction in ellipse area
  – ~8 km reduction in ellipse length
  – Magnitude of the improvement depends on landing site wind uncertainty and site elevation

• Given conservative engineering wind constraints, willing to sign up for **16 km x 14 km ellipse**
  – Best estimate: 12 x 11 km with MSL Gale-like winds
  – Baseline: 25 km x 20 km

• Maximum site elevation with range trigger: 0.0 km MOLA

• Key benefits:
  – Makes previously inaccessible landing sites accessible
  – Could save ~1 Earth year of driving
  – Makes the TRN job easier
TRN for Mars 2020

**Terrain Relative Navigation**
- Works by taking images during parachute descent and matching them to an onboard map
  - Uses a dedicated compute element, camera, and (maybe) an inertial measurement unit
  - Yields a position solution
- Performs terrain relative navigation while the spacecraft is priming the descent engines
- Executed by the Lander Vision System (LVS)

**Multi-Point Divert**
- Uses position solution and list of safe landing locations to select a landing target
- Augments original MSL backshell avoidance divert (requires slightly higher backshell separation altitude)
- Lives within MSL fuel and control authority constraints
### Preliminary Landing Site Access Results with TRN

**Partial List of SDT Suggested Landing Sites**

<table>
<thead>
<tr>
<th>Baseline (No TRN)</th>
<th>TRN with 40 m Accuracy</th>
<th>TRN with 60 m Accuracy</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE Syrtis Major</td>
<td>87.0%</td>
<td>99.5%</td>
<td>98.6%</td>
</tr>
<tr>
<td>E Margaritifer</td>
<td>87.8%</td>
<td>98.6%</td>
<td>97.1%</td>
</tr>
<tr>
<td>Nili Fossae*</td>
<td>95.5%</td>
<td>99.7%</td>
<td>99.4%</td>
</tr>
<tr>
<td>Ismenius Cavus</td>
<td>81.6%</td>
<td>94.2%</td>
<td>92.3%</td>
</tr>
<tr>
<td>Holden Crater Land-On Target*</td>
<td>96.1%</td>
<td>99.8%</td>
<td>99.6%</td>
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* Assumes a 14x16 km range trigger ellipse at touchdown

- TRN yields significant improvement in likelihood of safe landing
  - Maximum site elevation for TRN capability: approximately -1.0 km MOLA
  - Magnitude of improvement higher with better localization accuracy
  - Accuracy worse than 60 m greatly diminishes value of TRN

- For comparison: At time of selection, MSL final four landing site candidates all ~99% safe with respect to landing hazards
TRN and Go To vs. Land On

- Used Holden (MSL landing site finalist) to investigate converting a “go to” site to a “land on” site with TRN

- At Holden, TRN allows the ellipse to be moved down onto the go-to target
  - Minimal increase in terrain failure rate
  - ~12 km shift in center of ellipse

- May not work at all sites, but worth exploring for 2020 candidates
## EDL Constraint Summary

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<td><strong>Rock Cumulative Fractional Area</strong></td>
<td>≤ 0.5% chance of rock &gt; 0.55 m high in belly pan area; corresponds to ~8% rock abundance</td>
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<td>Exempt from rock/rover scale slope constraints in hazardous areas.</td>
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<td>≤ 110 m radius Separated from other hazardous areas by ≥ 120 m</td>
<td>New capability only provided by terrain relative navigation</td>
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- **M2020** refers to the baseline landing strategy.
- **Range Trigger** and **Range Trigger + TRN** are variations that include additional navigation capabilities.
- **MOLA** indicates elevation data from the Mars Orbiter Laser Altimeter.
Conclusions

• Without enhancements, EDL engineering constraints are almost identical to MSL constraints

• Landing site elevation capability improved by 2020 opportunity
  – But all other things being equal, lower is generally better

• Preliminary Mars Program future mission studies have not imposed any specific landing site constraints on Mars 2020

• Enhancements are feasible and provide significant landing site access improvement, but the project won’t pursue them without direction
  – Even if enhancements become part of the baseline, will want to carry at least one “safe haven” site that satisfies MSL-like constraints